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A Concept of Environmental Monitoring System Based on Triboelectric Generator

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Abstract **Today, the emergence of new technical means of monitoring the state of the environment based on modern approaches in the field of microcontroller technology is a tendency. First, it is necessary to emphasize the peculiarity of reducing the level of energy consumption for this type of devices, improving the quality of data communications (wireless communication), as well as the availability of components and their low cost in the market. An important feature of the effective functioning of the monitoring system is power sources. In this direction, the authors propose and develop new types of renewable energy converters, which are based on triboelectric and piezoelectric effects of ferroelectrics-semiconductors - $Sn_2P_2S_6$ type.**

I. Introduction

In real life, there often exists a need to determine the parameters of the environment. This is due to the growth of industrial emissions, an increase in the number of vehicles and global climate changes. Therefore, as never before, there is a growing need to develop systems for monitoring the state of our habitat. Serially produced telemetry systems of the environment are either too simple, and perform the functions of personal weather stations, or vice versa, are too complex, have large dimensions and weight. However, their use in both cases is complicated by an increased level of power consumption. Thanks to the development of a modern element base, primarily due to the reduction in the size and power consumption of various sensors and microcontrollers, it has become possible to develop miniature telemetry systems using alternative power supplies.

II. Description of the Measurement System – Hardware

We have developed a modular telemetry device (Fig.1). It allows us to determine the parameters of the environment. It contains a GPS module for geolocation; a level meter for α, β, γ radiation and ultraviolet radiation; sensors for the concentration of dangerous gases; temperature, atmosphere pressure and humidity. The received and preprocessed data through the built-in WEB server via the Wi-Fi interface are transmitted for remote monitoring and analysis. The information is also accumulated in a local secure drive based on a SD card. It acts as a personal "black box" for cases of emergency radio communication loss. The module is based on TI MSP-EXP430FR5994 [1] and Wi-Fi CC3100BOOST [2]. To provide the possibility of extending the functionality of the telemetry system, it is possible to connect additional modules via the Bluetooth LE interface. These can be dust meters, specific gas concentration detectors, and other rarely used sensors.

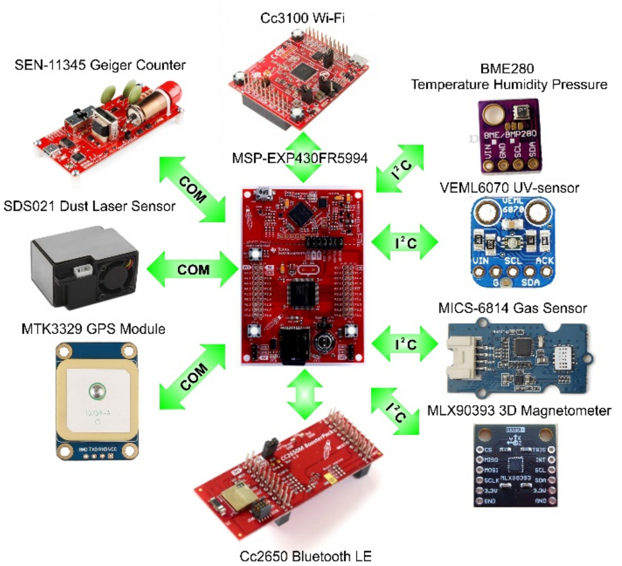

Figure 1. Structural diagram of the stand-alone device for environmental monitoring

The MSP-EXP430FR5994 LaunchPad™ is based on the ultra-low-power MSP430FR5x FRAM microcontroller platform. The board includes buttons and LEDs for quick integration of a simple user interface as well as two unique features: a microSD card slot allowing the user to interface with SD cards, as well as a super capacitor (super cap) that acts like a rechargeable battering, enabling stand-alone applications without an external power supply. The 16MHz MSP430FR5994 device features 256KB of embedded FRAM (Ferroelectric Random Access Memory), a non-volatile memory known for its ultra-low power, high endurance, and high speed write access. Combined with the 8 KB of on-chip SRAM, users have access to 264KB of memory to split between their data and code as they see fit. For example, a data logging application can greatly benefit from the fast, low power writes into FRAM – and all of that without fear of data-loss due to loss-of-power. The MSP430FR5994 includes the new Low-Energy Accelerator (LEA). This new hardware module delivers a fast, efficient, low-power vector math acceleration commonly found in digital signal processing (DSP) applications. This makes it easy for the MSP430 to process incoming analog data in real time. With benchmarks that outpace 32-bit ARM® Cortex®-

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M0+ MCUs by more than 40x, this nimble MCU delivers performance with exceedingly low power consumption. The device also includes a wide variety of integrated peripherals including communication ports, timers, real-time clock, AES encryption and CRC error-checking accelerators, as well as the analog comparator and a multichannel ADC with its ultra-low power, window-based interrupts.

The received and preprocessed data from sensors through the built-in WEB server via the Wi-Fi interface are transmitted for remote monitoring and analysis. The SimpleLink Wi-Fi CC3100 [2] solution provides the flexibility to add Wi-Fi to any microcontroller (MCU). This Internet-on-a-chip™ solution contains all you need to easily create IoT solutions, i.e. security, quick connection and cloud support.

As stated above, to provide the possibility of extending the functionality of the telemetry system, it is possible to connect additional sensors via the CC2650 Bluetooth LE module. Texas Instruments CC2650 SimpleLink™ Ultra-Low Power Wireless Microcontrollers are wireless MCUs that target Bluetooth Smart, ZigBee and 6LoWPAN, and ZigBee RF4CE remote control applications. These devices are members of the CC26xx family of cost-effective, ultra-low power, 2.4GHz RF devices. Very low active RF and MCU current and low-power mode current consumption provide excellent battery lifetime and allow operation on small coin cell batteries and in energy-harvesting applications. The CC2650 contains a 32-bit ARM Cortex-M3 processor running at 48MHz as the main processor and a rich peripheral feature set. This makes the CC2650 ideal for applications within a whole range of products including industrial, consumer electronics, and medical ones. The Bluetooth Low Energy controller and the IEEE 802.15.4 MAC are embedded into ROM and are partly running on a separate ARM Cortex®-M0 processor. This architecture improves overall system performance and power consumption and frees up flash memory for the application. The software tools, which were used for development, include Code Composer Studio (with unlimited possibilities and a huge library ready to use solutions), IDE Energia integrated development environment for Arduino compatible developments or MSPWare-Advanced system. To improve the energy efficiency there are separate optimizers such as EnergyTrace software.

III. ENERGY SUPPLY

A. *Energy converter*

To increase the autonomy of the environmental monitoring system, we have constructed an energy transducer for converting mechanical energy (vibration and motion) into electric current.

There exist many of motion energy-harvesting techniques based on various physical principles: piezoelectric, triboelectric, electromagnetic, electrostatic and others. However, unfortunately, the direction of mechanical movement, which can be harvested by a triboelectric [3] or piezoelectric [4] energy generator, is usually limited to a single direction. Therefore, the development of devices that do not depend on the direction of movement is very popular in the market [5]. In addition, due to small efficiency of each of transformation principles, many systems working simultaneously use multiple conversion methods [6].

We created a combined triboelectric-piezoelectric generator, which uses a ferroelectric $Sn_2P_2S_6$ powder as an active material. If triboelectrically [7] or piezoelectrically [8] charged particles can move freely in any direction within suitably placed electrodes (Fig.2.), it will be possible for an energy harvester to generate electrical energy regardless of the direction of movement due to its inherent freestanding feature.

TABLE I.
TRIBOELECTRIC SERIES

- Negative					Positive +				
Teflon	Polyethylene	Acrylic	Gold	Copper	Amber	Wood	Silk	Wool	Glass

The generator-cell consists of a cube made of an insulator, opposite inner sides of which are coated with nanostructured aluminum or copper electrodes (Figure 2). The 20% of cell contains $Sn_2P_2S_6$ ferroelectric powder (with ~50-100 microns of particle size). The minimum size is limited by the piezoelectric parameters of particles. 3 pairs of electrodes are connected to AC-DC converter and then to the voltage driver and energy storage (battery or supercapacitor). In the presence of external vibrations, powder particles rub against the electrodes. Due to the triboelectric effect, the electric current is generated. The additional charge on the surface of ferroelectric particles is accumulated thanks to the piezoelectric effect. The correct orientation of polarized particles is realized automatically due to electrostatic interactions with charged electrodes.

Potential of electrodes, due to triboelectric effect, can be calculated by formula

$$U = \sigma \cdot d / \varepsilon_0 ,$$

where σ is the triboelectric charge density, ε_0 is the vacuum permittivity, and d is the interlayer distance.

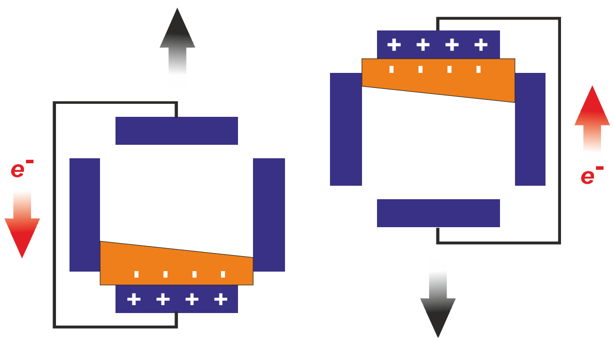

Figure 2. Generating of current at motion of powder

The peculiarity of the piezoelectric properties of $Sn_2P_2S_6$ crystals is that all longitudinal and transverse components of piezoelectric tensor d_{1j} and d_{3j} have the same sign. This suggestion results from the fact that the spontaneous deformation along [100], [010] and [001] axis is of the same sign. Because of this, both components of hydrostatic piezoelectric effect $d^1_h = d_{11} + d_{12} + d_{13}$ and $d^3_h = d_{31} + d_{32} + d_{33}$ reach high values since they represent the additive sum of longitudinal and transverse piezoelectric coefficients. Charge on the surface of particle, due to piezoelectric effect, can be calculated by formula

$$q=d_h F\ ,$$

where F is the force which acts on the particle, d_h is the hydrostatic piezoelectric coefficient (for $Sn_2P_2S_6$ $d^1{}_h$=244 pC/N, and $d^3{}_h$=91 pC/N).

The fluid-like characteristic of the powder removes restrictions on the geometric design of the container. There exists a possibility to create generators with various forms: cube, sphere, cylinder, tube. The size of device may vary from 5x5x5mm^3 (or smaller) to 0.5x0.5x0.5m^3 (or bigger).

The main advantages of the proposed generator are waterproof, insensitive to the direction of motion, high efficient, durable, scalable.

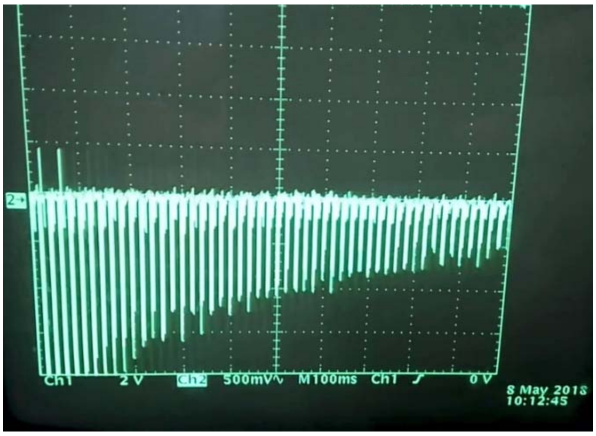

Figure 3. Attenuated (1:100) output voltage of $Sn_2P_2S_6$ powder-based triboelectric nanogenerator.

The 100 times attenuated output voltage of one cell of $Sn_2P_2S_6$ powder-based triboelectric nanogenerator was shown on figure 3. The typical output voltage of the cell with size 1x1 cm is 180-200 V and the maximum current is 10-15 μA.

Moreover, it is possible to significantly improve the efficiency of such a generator with increasing the number of cells in a multidimensional matrix of the type shown in Figure 4. The number of cells in the matrix can be adjusted depending on the power demand and the limit on the geometric size of the entire generator. Cells can be made using 3D printing, followed by deposition of copper electrodes. Thus, it is possible to create transformations of the power source for a particular application. Preliminary experiments on this scheme give positive results. Also, the authors consider increasing the effectiveness of such a generator due to the use of additional physical properties of the working powder of a ferroelectric. The pyroelectric and photovoltaic effects of this semiconductor are supposed to be involved. For this, it is necessary to solve a number of practical problems for such a generator.

B. Energy harvesting system

To connect the primary converters (triboelectric, piezoelectric, photoelectric, etc.) to the load, special electronic circuits, called Energy Harvesters, have been developed. In this connection, we want to present some of them from the Liner Technology company. The first is represented by the module LTC3330 [9]. In the presence of at least one current source, this chip provides power to the load from it instead of the Li-Ion battery (which serves as a backup power source) (Fig. 5).

The second module LTC4079 is a linear charger for low power applications [10].

To achieve the best performance, the LTC3330 uses the maximum power point tracking technology. When using non-rechargeable galvanic elements together with the battery/capacitor the LTC3330 has a built-in optimization mechanism, which makes the life time of the battery longer. To ensure point management of the application, the LTC3330 has 4 independent power outputs, as well as sleep mode with the ability to disable all or only some sources of energy. An important feature of the module is an intelligent power management:

- consumption of 25 nA in the control mode,
- 3 auxiliary inputs,
- programmable output voltage,
- alarm function - internal counter or external event.

The advantages of the LTC3330 in comparison with competitors are substantially better conditions for a cold start, efficiency, less consumption.

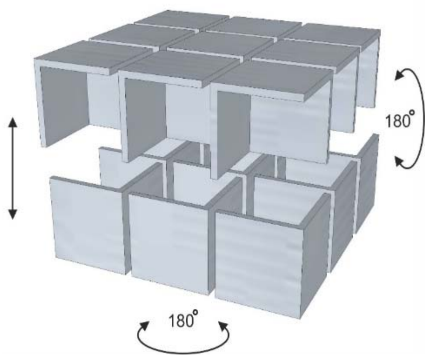

Figure 4. 3D-view of the structural units of the generator, twice deployed for 180 degrees.

Separately we want to note the advantages of ionistors (supercapacitors) [11]. Here are the main ones. First, unreality to the differences of the external temperatures, fast charging, a large number of charge-discharge cycles (1 million or 30,000h). The first property is especially valuable for monitoring autonomous systems where the possibility of stable operation under extreme external conditions is very important.

Among the disadvantages of supercapacitors we can name a relatively large leakage current (self-discharge), high price and low operating voltage. However, a huge number of manufacturers are working on solving these problems by improving the parameters of ionistors.

The usage of modern ultra-low power sensors and microcontrollers allows us to offer the concept of creating stand-alone devices for monitoring the environment by alternative renewable energy converters.

Our proposed system is designed to provide a scalable, efficient and compact solution that integrates multiple sensors into a single, easy-to-deploy unit. These compact, easy to install environment monitor devices collect and analyze air quality parameters, ionizing radiation levels and other physical quantities. At a fraction of the volume of a traditional environmental monitoring station, our equipment is suitable both for fixed and mobile installation. Remote device management and data access are made simple with web interfaces and mobile apps; information such as hourly and daily averages is automatically computed; data can also be exported to external programs to perform more sophisticated statistical analysis.

Using a local storage of collected data makes it possible to operate the system in full offline mode. This is also provided by alternative energy sources that convert the movement of wind or water into electricity, which, when sealed, makes it possible to install our device on ships, boats or floating platforms.

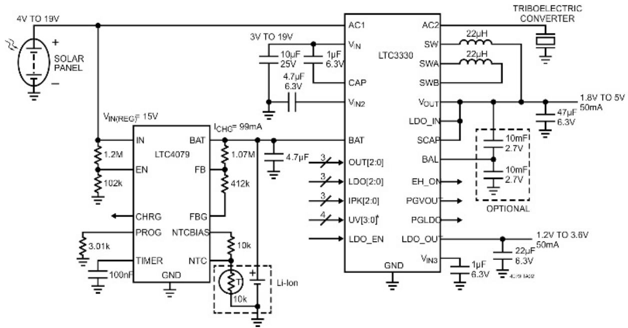

Figure 5. Simplified schematic of LTC3330 energy harvester circuit with LTC4079 linear charger [9,10].

The main difference of our concept from widely used nowadays is the use of very affordable, cheap and micro power components. Compared to serially produced weather stations, the proposed system will cost 10 times cheaper and take 10 times less space. It is quite possible to offer it as a personal monitoring system for the state of the environment, without claiming high metrological parameters.

IV. CONCLUSIONS

The usage of modern ultra-low power sensors and microcontrollers allows us to offer the concept of creating stand-alone devices for monitoring the environment by alternative renewable energy converters.

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